Assessing the uncertainty in permafrost lake margin detection from varying spatial resolution Synthetic Aperture Radar (SAR)

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Scott Polar Research Institute
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GEO

VIENNA UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF GEODESY AND GEOINFORMATION
RESEARCH GROUPS PHOTOGRAMMETRY & REMOTE SENSING

Why monitor permafrost lakes?

Why monitor permafrost?

- Permafrost is an indicator of climate change
- Thawing permafrost is a carbon source
- Transport in Arctic and sub-Arctic areas (roads, railways, pipelines) is affected by permafrost degradation
- Thawing of permafrost in alpine areas raises the risks of geohazards

Permafrost ground thermal regime changes due to:

- Changes in air temperature and/or
- Surface disturbances

- Precipitation
- Clearing of vegetation
- Removal of insulating organic layer
- Forest fires
- River channel migration
- Shoreline erosion

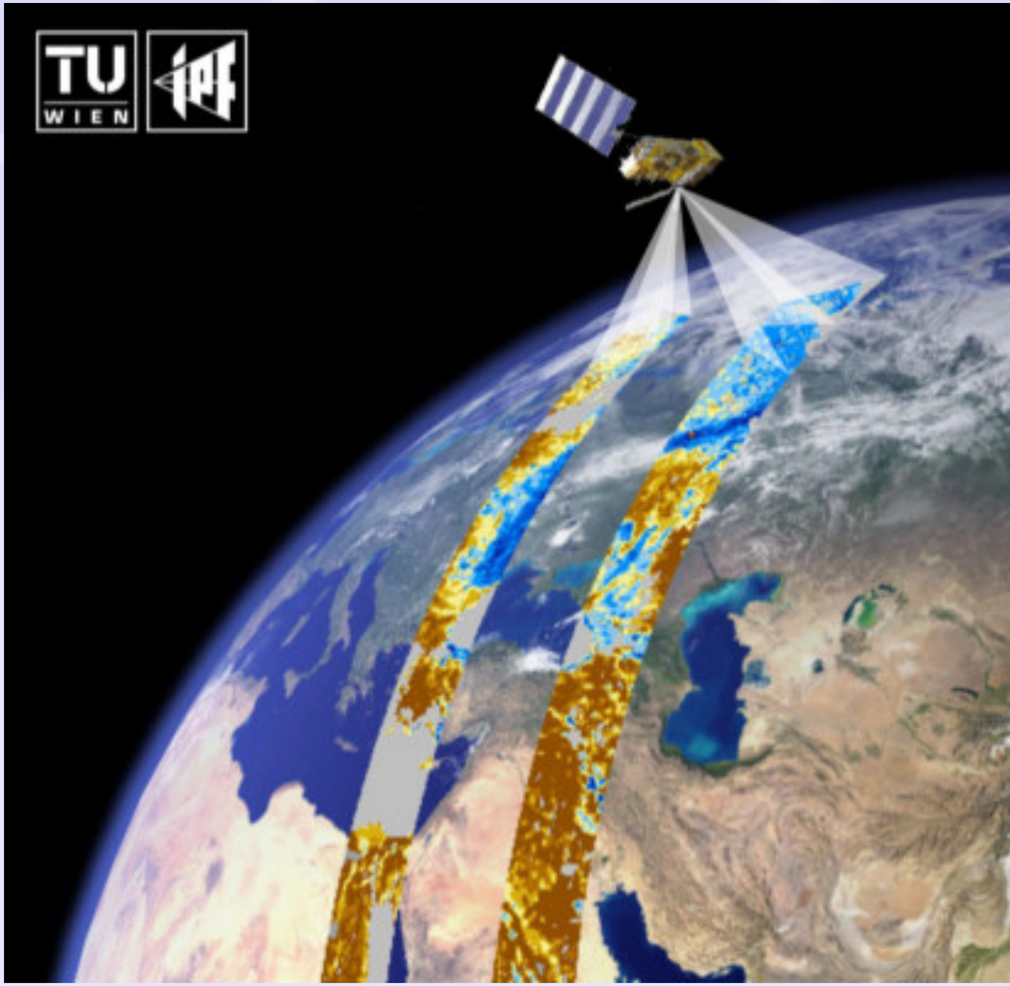
Response of Permafrost to climate change depends on variations in local seasonal factors:

- Snow cover
- Vegetation
- Surficial material
- Moisture content
- Drainage

Permafrost & Remote Sensing

Cannot directly see below the soil surface, but need to monitor indicators:

- Land-surface hydrology
- Terrain changes
- Vegetation



Land-surface hydrology

- Surface soil moisture (SSM)
  - soil moisture influences heat transfer
  - Indicative for drainage conditions
- Lakes (water bodies - WB)
  - Indicative for thermokarst processes, permafrost degradation
- State transition (freeze/thaw timing – FT; surface state flag - SSF)
  - Complements land surface temperature
  - Can serve as masking input for SSM

- Related Work:

  Smith et al. 2005

  in Science

BREVIA

Disappearing Arctic Lakes

L. C. Smith,[1*] Y. Sheng,[2] G. M. MacDonald,[1] L. D. Hinzman[3]

Arctic warming has accelerated since the 1980s, driving an array of complex physical and ecological changes in the region (*1*). Particularly puzzling has been evidence for perturbations to the terrestrial water cycle (*2*), which plays an integral role in nearly every aspect of the Arctic system. We compared satellite imagery acquired across ~515,000 km² of Siberia in the early 1970s with recent (1997 to 2004) satellite data to inventory and track ongoing changes in more than 10,000 large lakes after three decades of rising soil and air temperatures in the region (*1*, *3*, *4*). Our analysis reveals a widespread decline in lake abundance and area, despite slight precipitation increases (*4*). The spatial pattern of lake disappearance strongly suggests that thawing of permafrost is driving the observed losses.

Between 1973 and 1997–98, the total number of large lakes (those >40 ha) decreased from 10,882 to 9712, a decline of 1170 or ~11% (SOM text). Most did not disappear altogether, but instead shrank to sizes below 40 ha. Total regional lake surface area decreased by 93,000 ha, a ~6% decline. One hundred and twenty-five lakes vanished completely and are now revegetated, as indicated by sharp increases in near-infrared reflectance (Fig. 1, B and C). Sub-

ronments, driven primarily by slumping and collapsed terrain features (thermokarst) that subsequently fill with water (SOM text). Such observations are in apparent conflict with the phenomenon seen here and also near Council, Alaska, where thermokarst ponds in discontinuous permafrost are also shrinking (*5*).

rather than a direct climatic mechanism such as increased evaporation). It also raises the possibility of a diffuse lake drainage "front" where warming permafrost first experiences widespread degradation. The fact that ~85% of the vanished lakes reported here occur within 200 km of the continuous permafrost boundary lends some support to this concept (Fig. 1A).

Clearly, other factors besides permafrost influence substrate permeability and lake drainage. In west Siberia, shallow water tables and extensive, low-permeability peatlands (*6*) ensure continued survival of many lakes, even where permafrost is absent. Overlay of our lake maps with a detailed peatland inventory (*7*) shows that, although lakes in continuous permafrost are found on all substrates, they exist only as perched systems on peatlands further south. In such regions, factors besides permafrost degradation will be important to lake persistence. However, aside from low-permeability environments and/or beneficent water balance adjustments (i.e., further increases in net precipitation), the ultimate effect of continued climate warming on high-latitude, permafrost-controlled lakes and wetlands may well be their widespread disappearance.

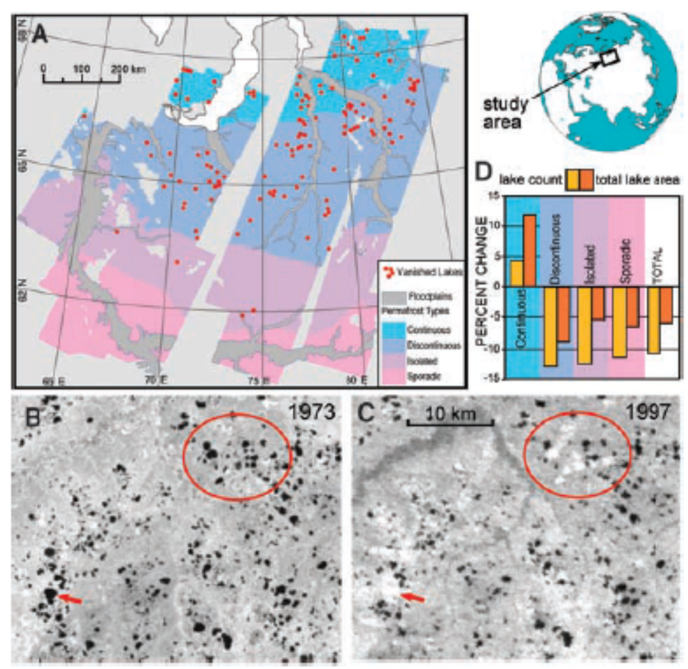


Fig. 1. (A) Locations of Siberian lake inventories, permafrost distribution, and vanished lakes. Total lake abundance and inundation area have declined since 1973 (B), including (C) permanent drainage and revegetation of former lakebeds (the arrow and oval show representative areas). (D) Net

References and Notes

1. M. C. Serreze *et al.*, *Clim. Change* **46**, 159 (2000).
2. B. J. Peterson *et al.*, *Science* **298**, 2171 (2002).
3. A. V. Pavlov, N. G. Moskalenko, *Permafrost Periglac. Process.* **13**, 43 (2002).
4. K. E. Frey *et al.*, *Polar Res.* **22**, 287 (2003).
5. K. Yoshikawa, L. D. Hinzman, *Permafrost Periglac. Process.* **14**, 151 (2003).

- Related Work:

Smith et al. 2005 in Science

Karlsson et al. 2012 in Journal of Hydrology

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Disappearing Arctic Lakes

L. C. Smith,[1*] Y. Sheng,[2] G. M. MacDonald,[1] L. D. Hinzman[3]

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Thermokarst lake, hydrological flow and water balance indicators of permafrost change in Western Siberia

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A R T I C L E   I N F O

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Catchments
Climate change
Water storage change

S U M M A R Y

Permafrost, mainly of discontinuous type, that underlies the tundra and taiga landscapes of the Nadym and Pur river basins in northwestern Siberia has been warming during the recent decades. A mosaic of thermokarst lakes and wetlands dominates this area. In this study we tested the hypothesis chain that permafrost thawing changes thermokarst lake area and number, and is then also reflected in and detectable through other associated hydrological changes. Based on indications from previous studies, the other hydrological changes in a basin were expected to be decreasing intra-annual runoff variability (quantified by decreasing maximum and increasing minimum runoff) and systematically decreasing water storage. To test this hypothesis chain, we mapped thermokarst lake changes using remote sensing analysis and analyzed both climate (temperature and precipitation) and water flow and balance changes using available monthly data records. This was done for the whole Nadym and Pur river basins and a smaller sub-basin of the former (denoted 7129) with comparable data availability as the whole river basins. The results for the 7129 sub-basin show all the indicators (thermokarst lake and other hydrological) changing consistently, as could be expected in response to permafrost thawing that alters the connections between surface and subsurface waters, and leads to overall decreases in water (including ground ice) storage within a basin. Over the Nadym and Pur basins, the relative area influenced by similar permafrost thawing and associated lake and hydrological effects appears (yet) too small to be clearly and systematically reflected in the basin-average indicators for these large basins.

- Research: Monitor extent and dynamics of spring floods

- Motivation: Inter-annual changes in water body extent remain inconspicuous.

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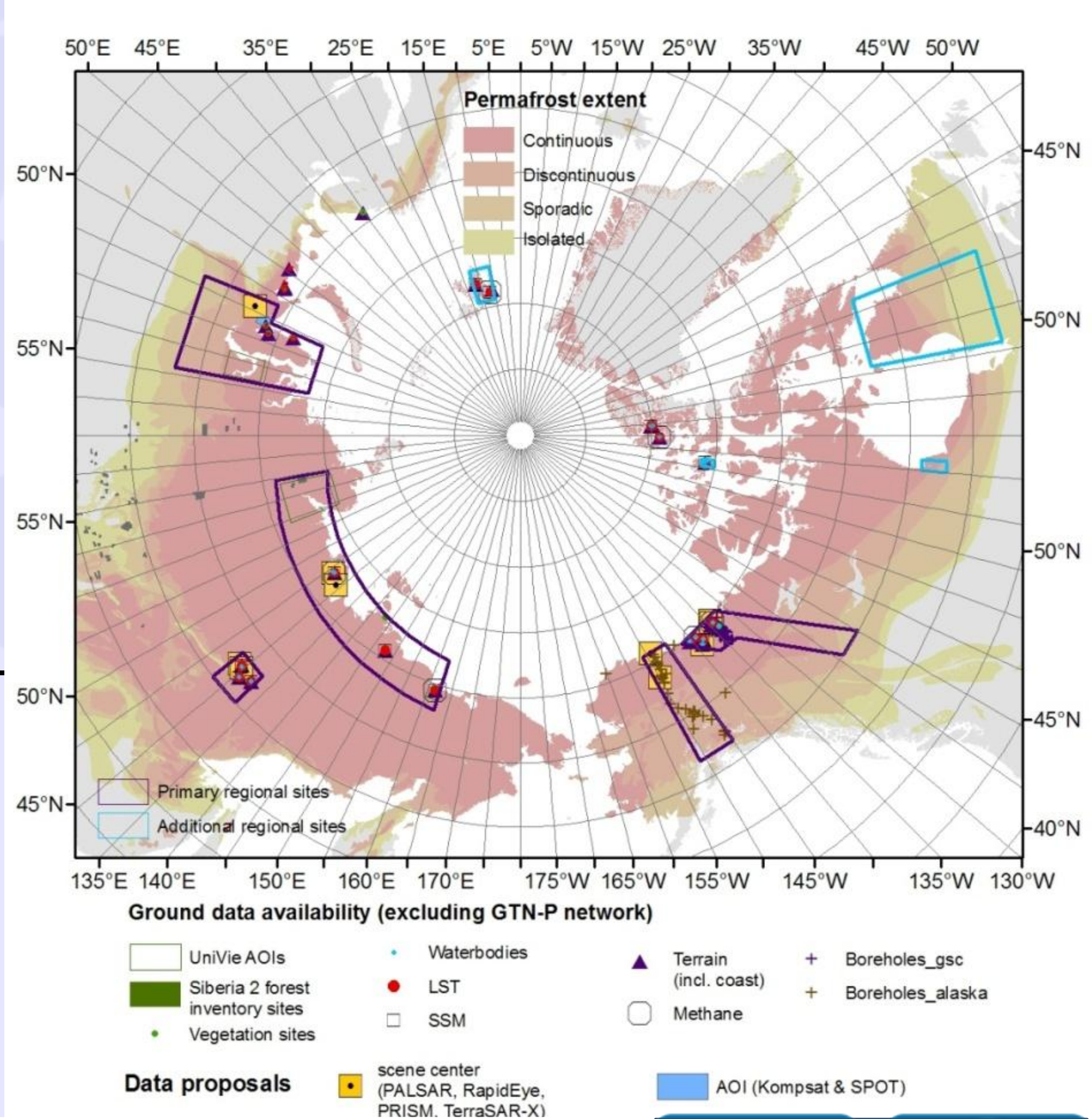
"Spring flood can start and end at different dates and its duration may vary significantly from one year to another, and thus some of the interannual variability of snowmelt is hidden when monthly or annual averages are used." **Zakharova et al. (2011)**

Snow Cover and Spring Flood Flow in the Northern Part of Western Siberia (the Poluy, Nadym, Pur, and Taz Rivers)

E. A. ZAKHAROVA,[*,+,#] A. V. KOURAEV,[*,#] S. BIANCAMARIA,[*,+,&] M. V. KOLMAKOVA,[*,@]
N. M. MOGNARD,[*,&] V. A. ZEMTSOV,[@] S. N. KIRPOTIN,[@] AND B. DECHARME[**]

Regional lake monitoring

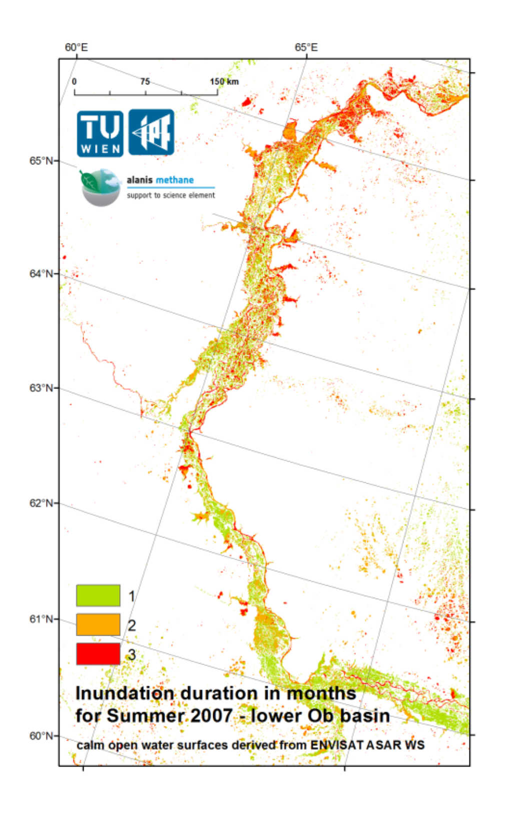
- Medium scale monitoring is possible by use of SAR (radar) data.
- Fairly good coverage: ENVISAT ASAR Wide Swath:
  - 120 m resolution
  - Open water surfaces detectable
- Annual maps of open water/ water fraction (summer stage – July-August) since 2007 + number of acquisitions

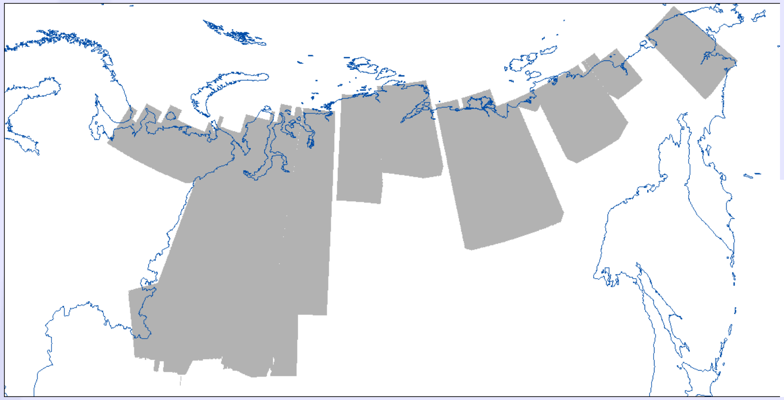


Welcome to the Website of the Project
DUE PERMAFROST

Regional water bodies

- Seasonal dynamics for Northern Eurasia will become available from ESA STSE ALANIS
- www.alanis-methane.info
- Specification
  - 10 day steps with update flag
  - 2007 and 2008
  - Coverage: parts of northern Eurasia





‘Local’ wetlands product

alanis methane
support to science element

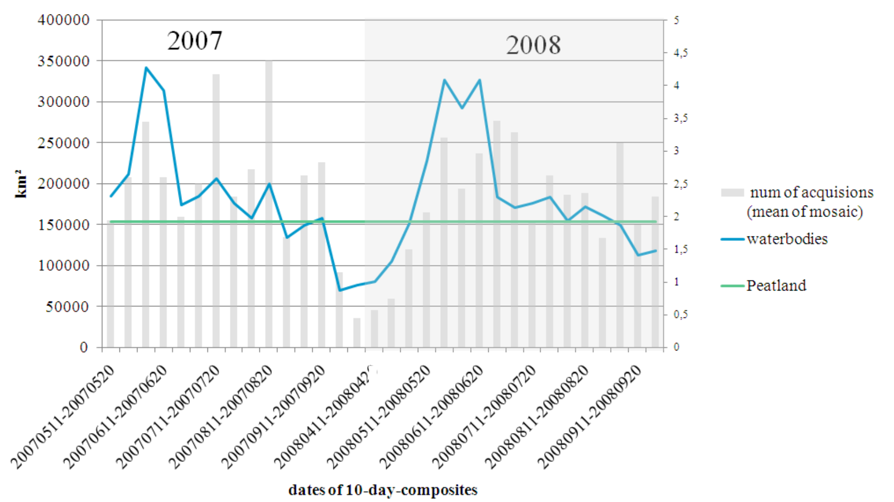
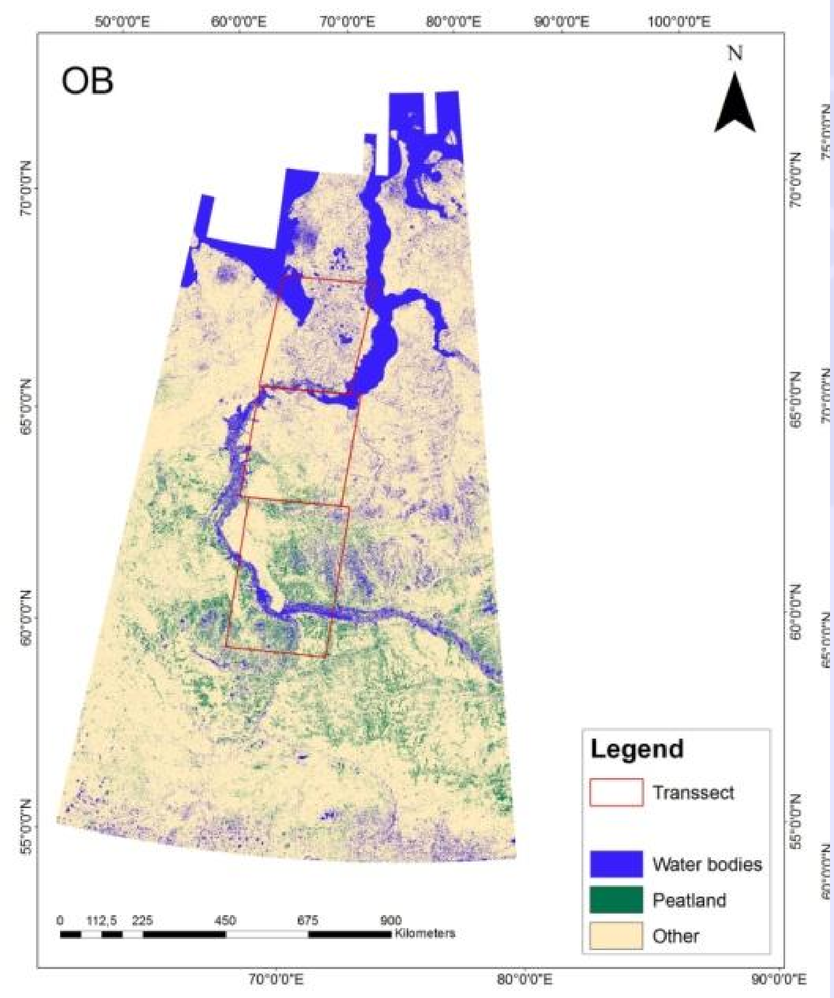
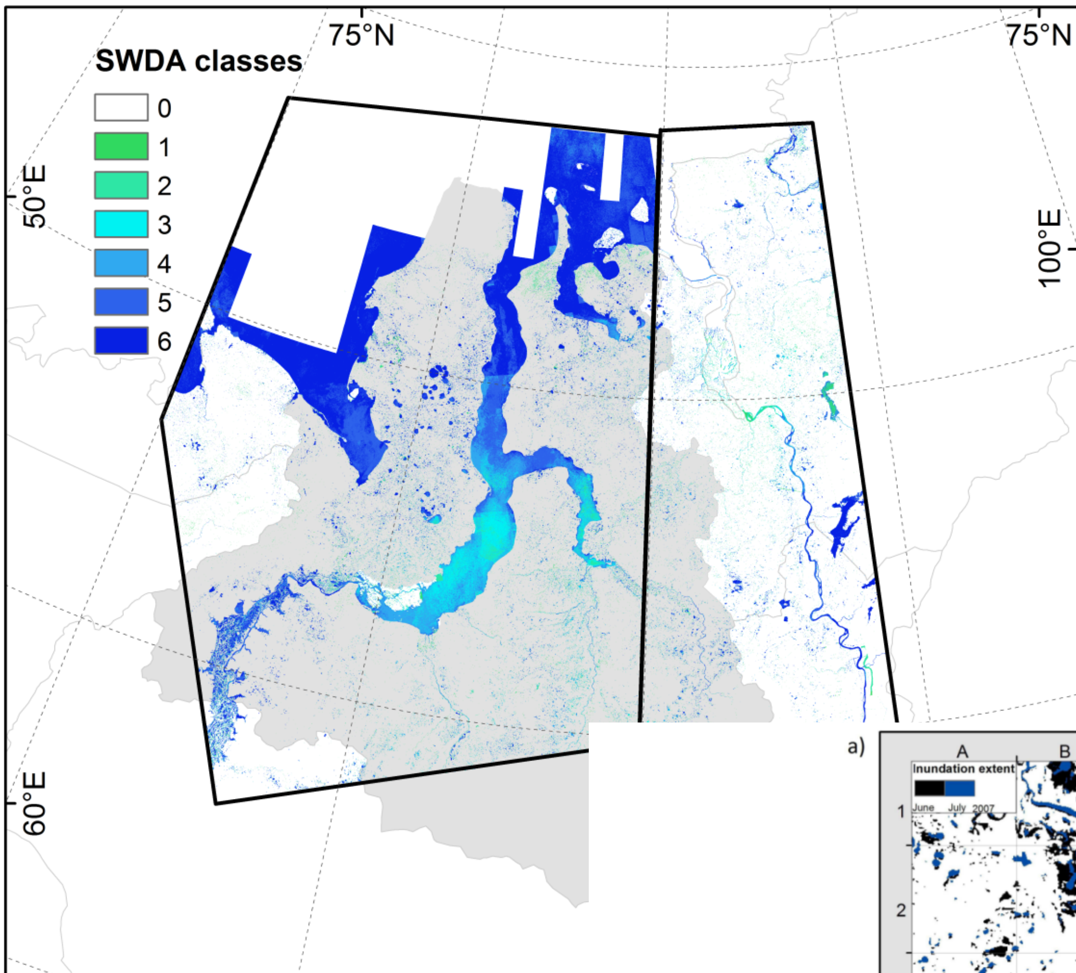
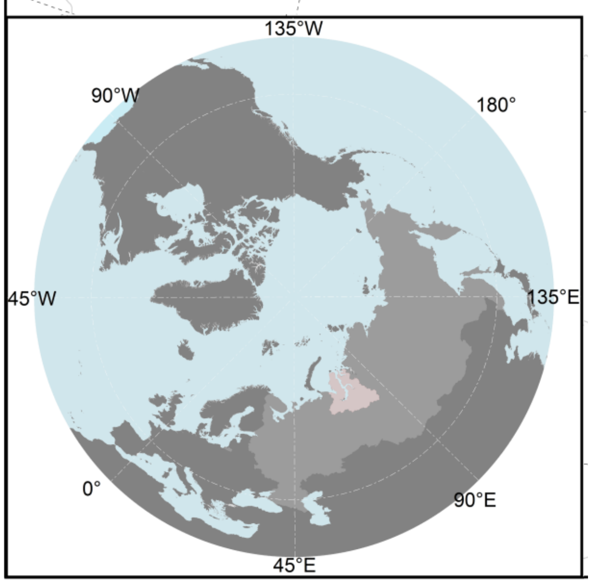


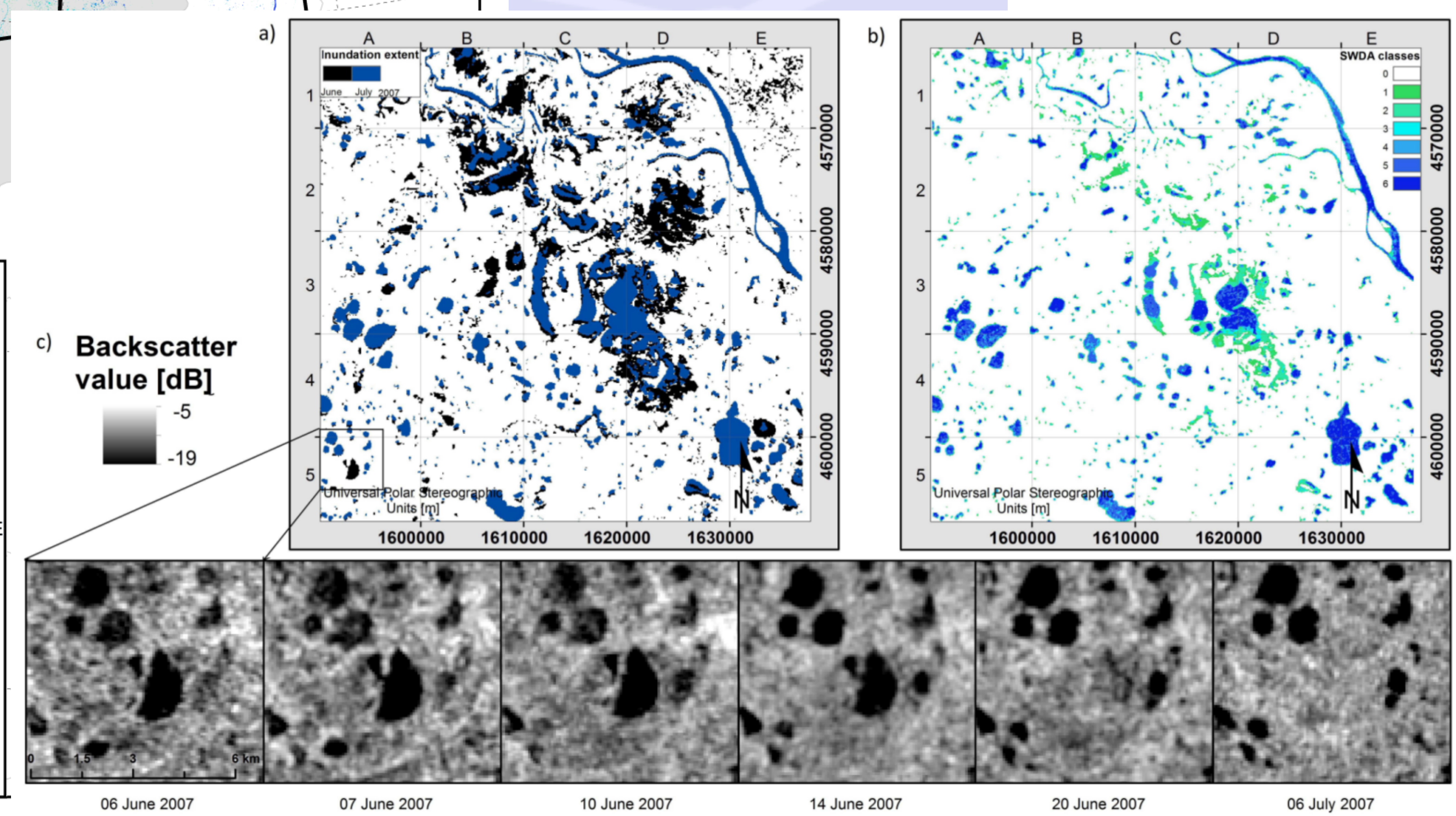
Figure 7: Temporal inundation dynamics of water bodies (blue) in relation with peatland area (green) in a **Ob river** basin and delta derived from ASAR WS data of 2007 and 2008.

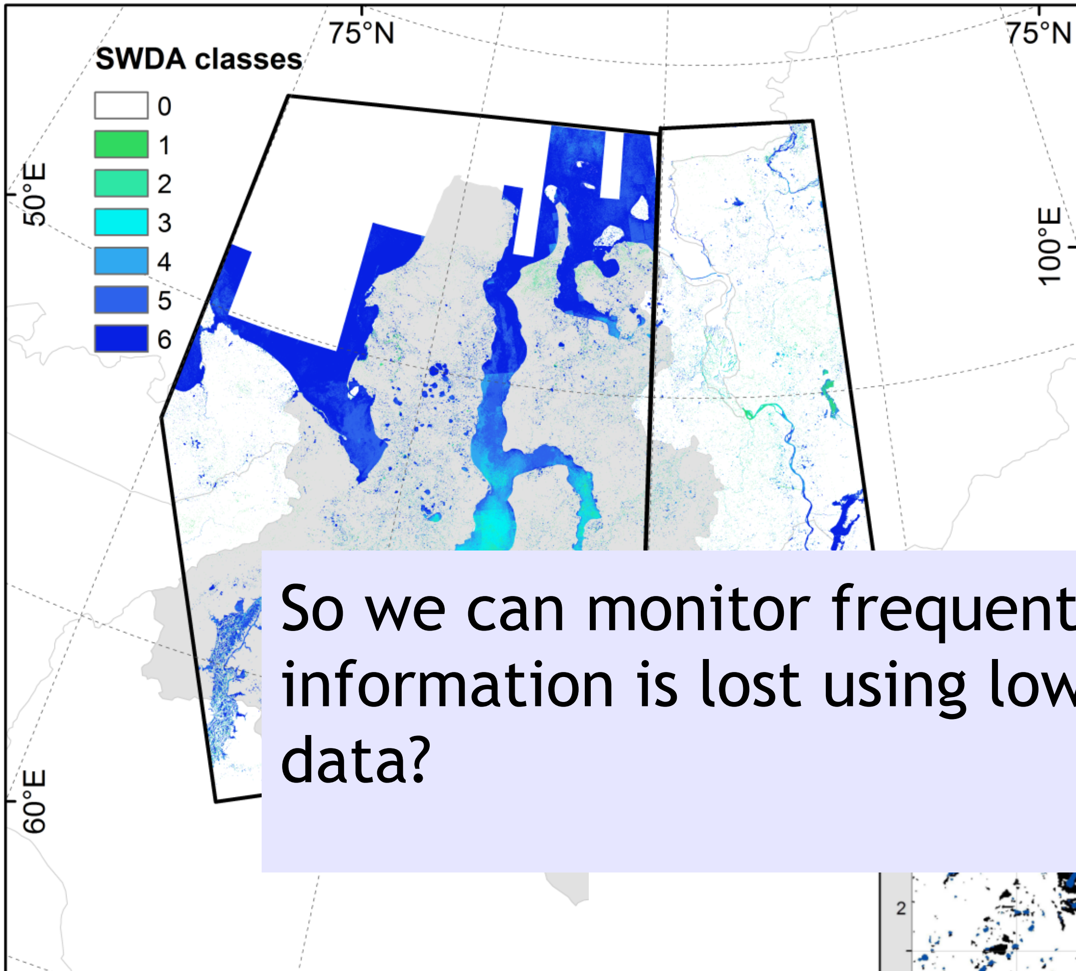


Surface Water Dynamics Algorithm (SWDA) developed to highlight and quantify spring flood and retreat (Trofaier et al. 2013).





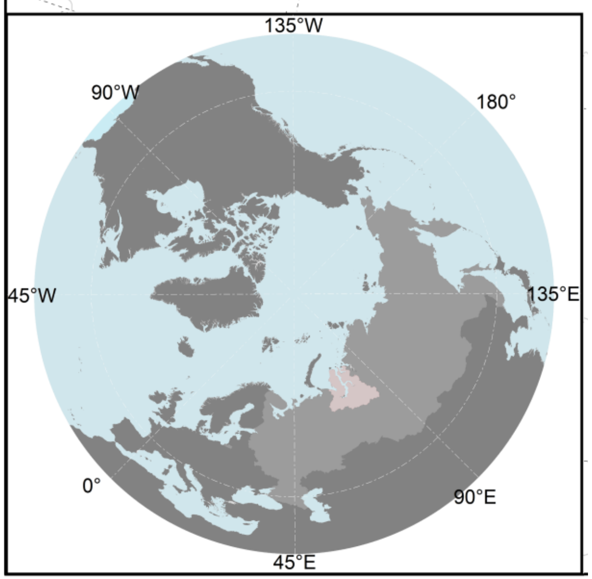


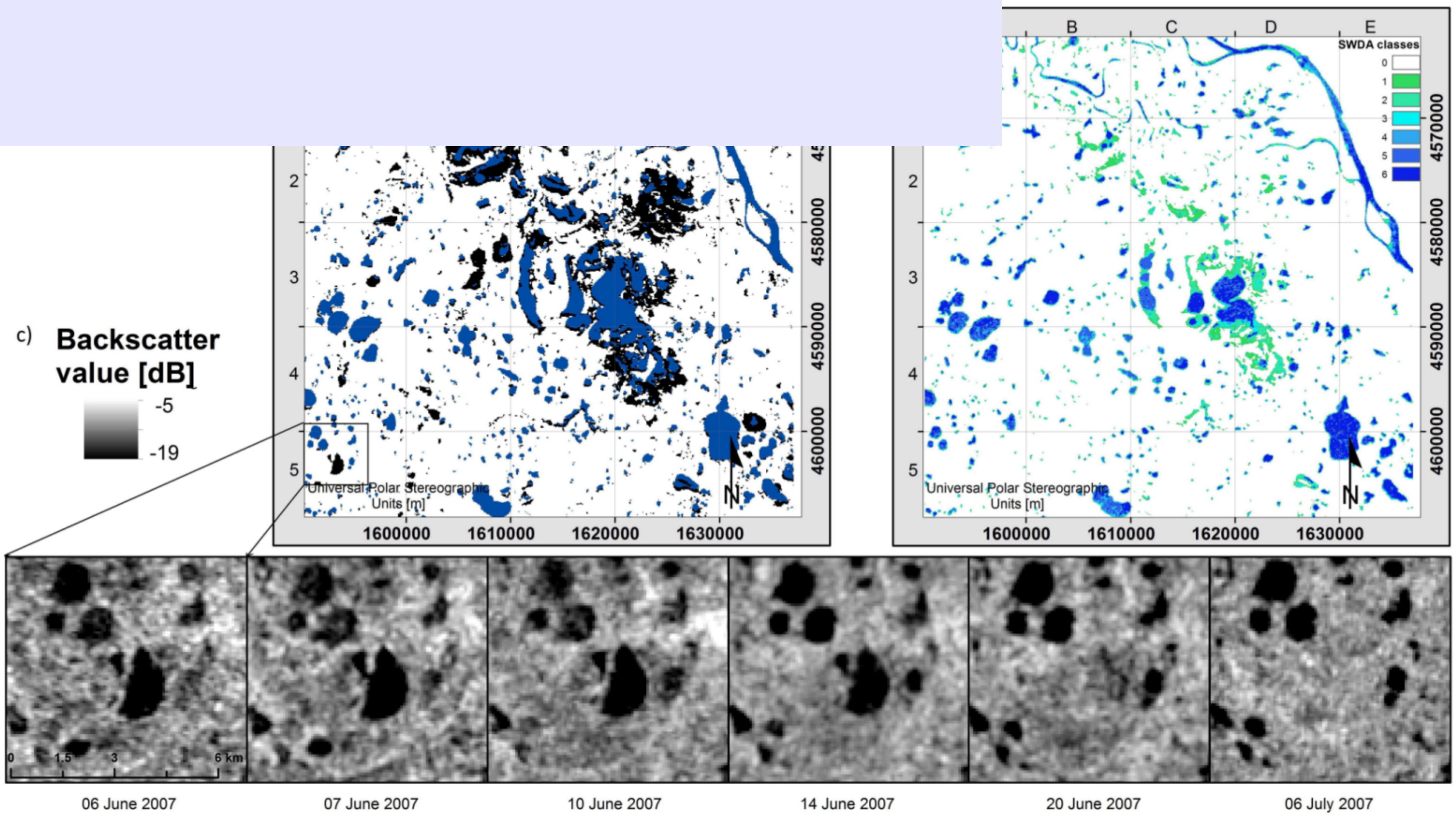


Surface Water Dynamics Algorithm (SWDA) developed to highlight and quantify spring flood and retreat (Trofaier et al. 2013).

So we can monitor frequently, but how much information is lost using low spatial resolution data?

alanis methane
support to science element





Yamal Peninsula

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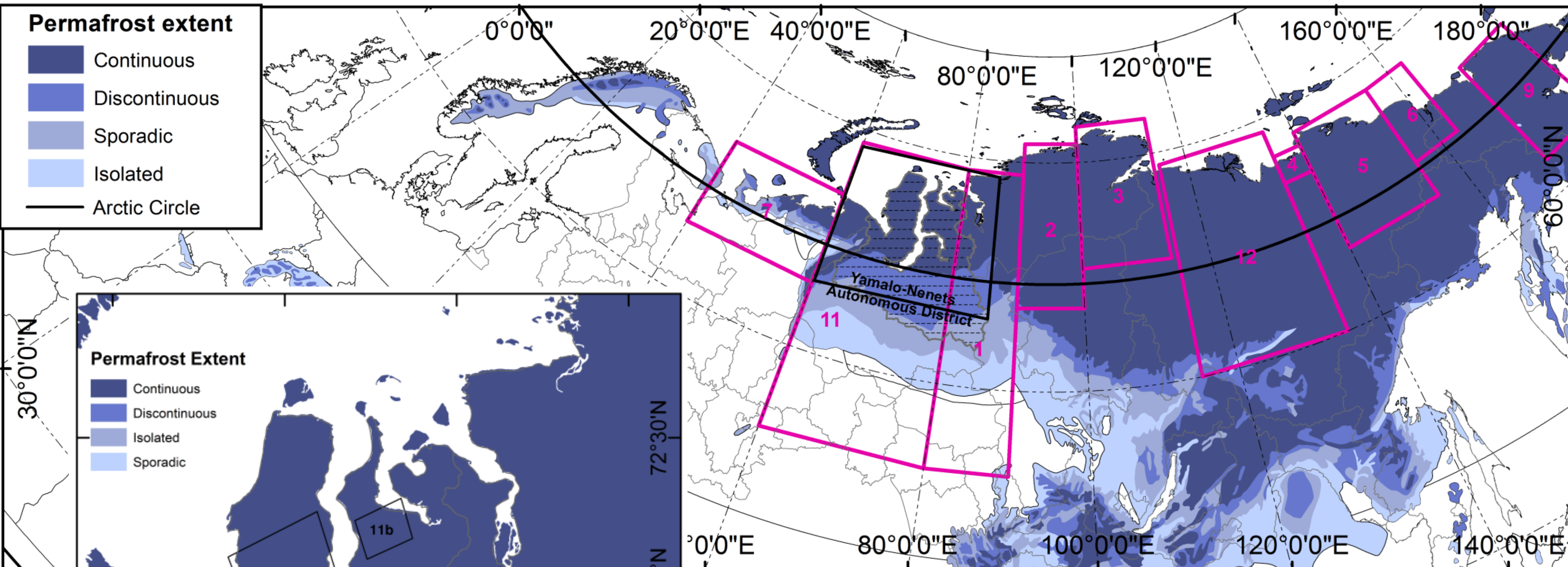
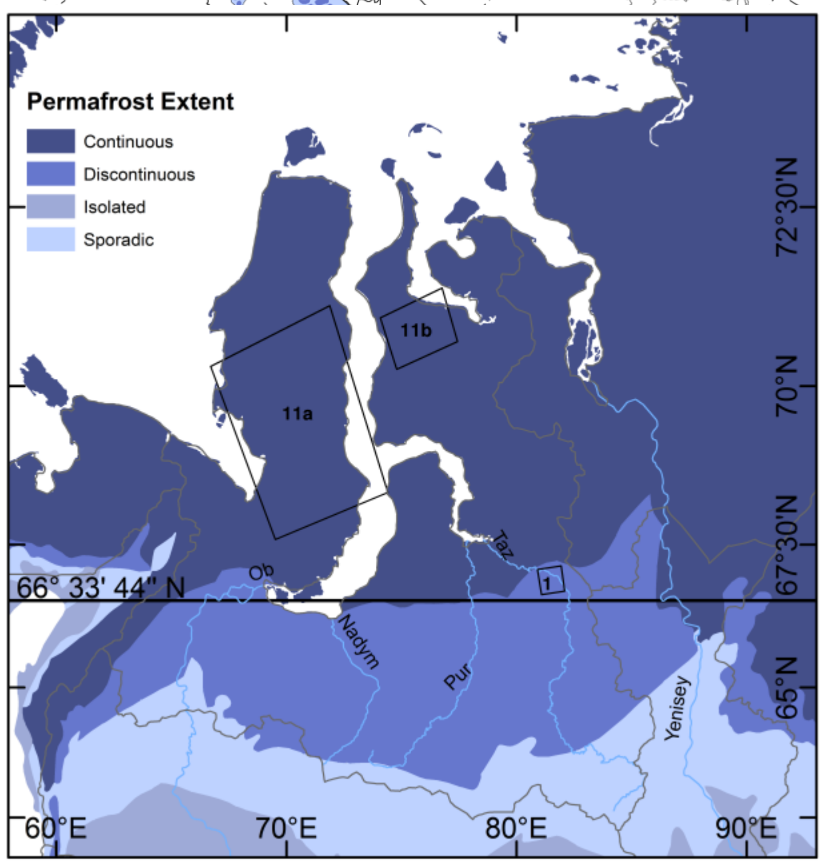




Why Russia?
>60% is underlain by permafrost

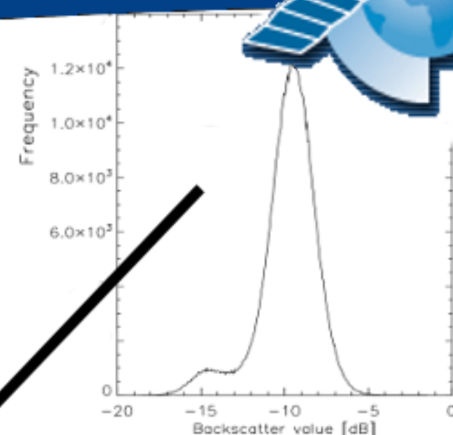
Why Yamal?
Identified to be one of the areas of high susceptibility both to climate-induced changes and human activities

Active Microwave Data:

Ideally suited for monitoring surface hydrology.
-Active: Independent of solar illumination
-Cloud penetration

Straightforward water body classification method:

Specular reflection of the incident radar beam leads to a bimodal backscatter distribution. Open surface water is associated with low backscatter values.



ENVISAT ASAR

Wide Swath Mode
C-band, λ = 3.8 – 7.5 cm
5.331 GHz centre frequency
75 m pixel spacing (150 m spatial resolution)
HH (or VV) polarisation

Thresholding:

Classification of water bodies through thresholding.
Bartsch et al. 2008:

89 © IWA Publishing 2008 Hydrology Research | 39.2 | 2008

Detection of permanent open water surfaces in central Siberia with ENVISAT ASAR wide swath data with special emphasis on the estimation of methane fluxes from tundra wetlands

Annett Bartsch, Carsten Pathe, Klaus Scipal and Wolfgang Wagner

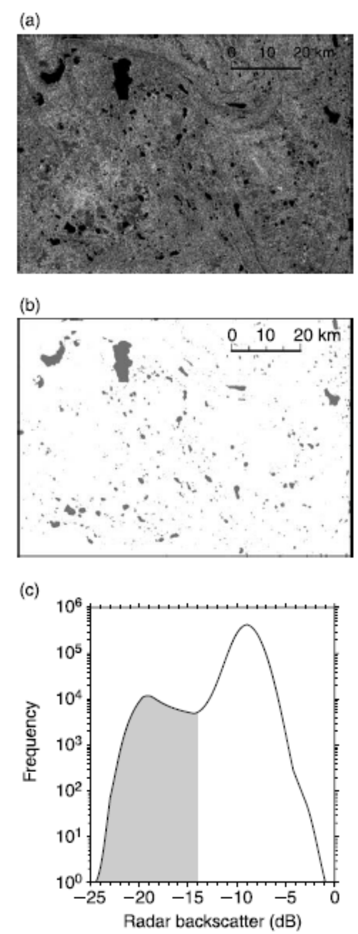


Figure 3 | Threshold classification example of a tundra site: (a) grayscale normalized image, (b) classified image with lakes in gray and (c) histogram of normalized backscatter in dB.

Lakes from ENVISAT ASAR WS - Known problems (i)

- C-Band – sensitivity to weather in case of this specific application
- Number of acquisitions – all available data independent from weather condition!
- Up to 60% of data affected
- Investigated within ESA STSE ALANIS Methane

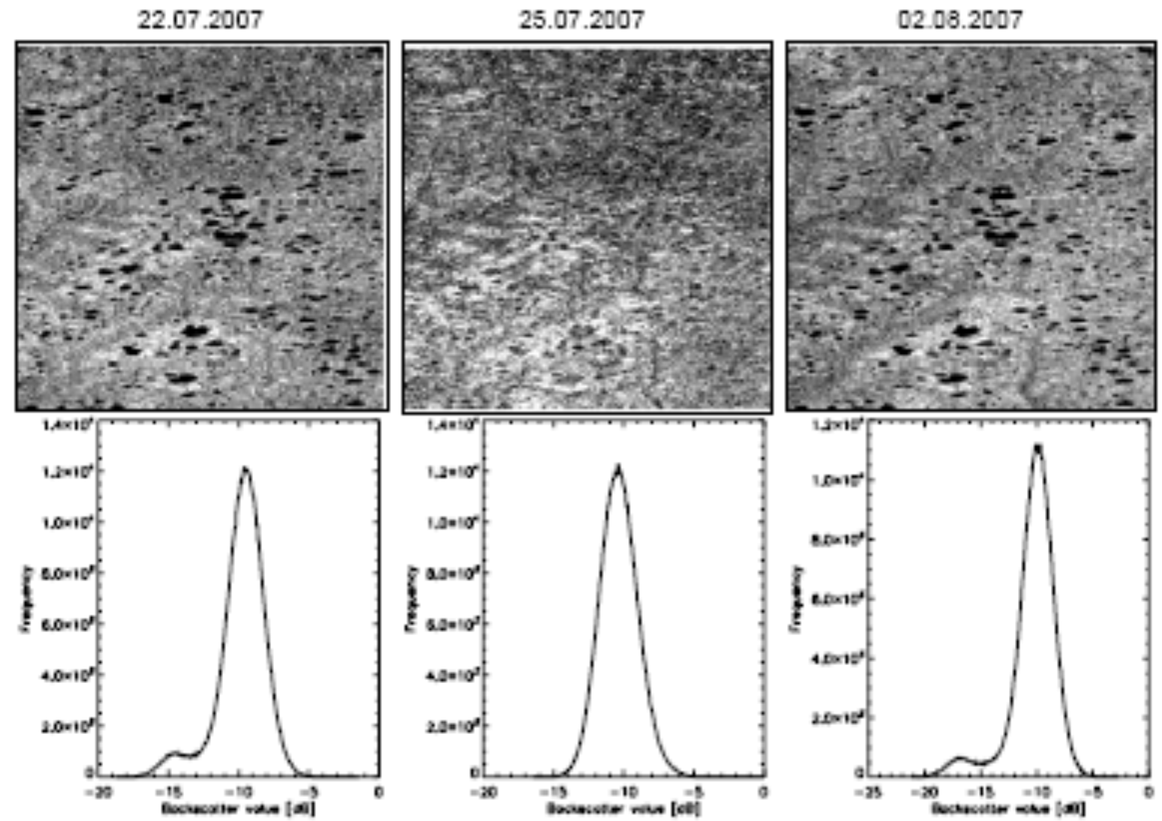


Fig. 3. Backscatter time series example for loss of bimodal distribution over tundra: top normalized backscatter images, bottom: histograms of backscatter distribution [dB].

Bartsch et al. 2012

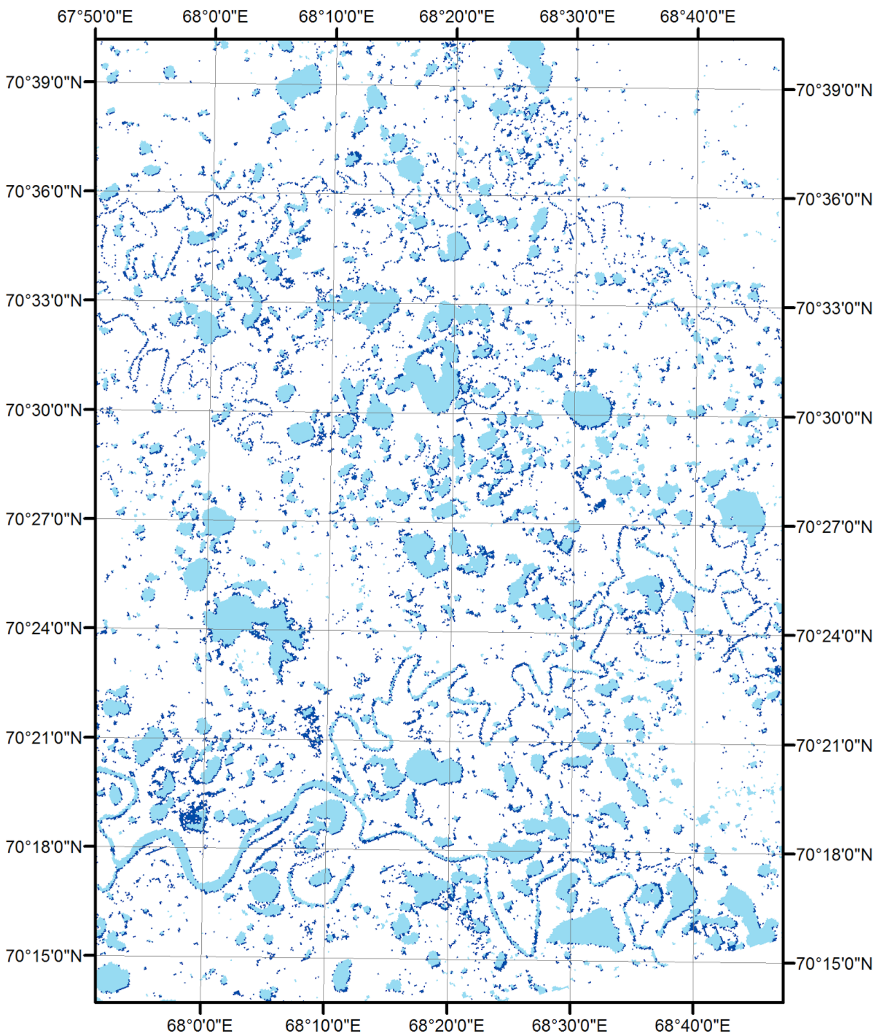
alanis methane
support to science element

Lakes from ENVISAT ASAR WS - Known problems (ii)

Radar – sensitivity (in particular C-Band) to vegetation results in double bounce rather than specular reflection.

Trofaier et al. 2013

Assessment of wavelength impact and lake size



a)

water bodies

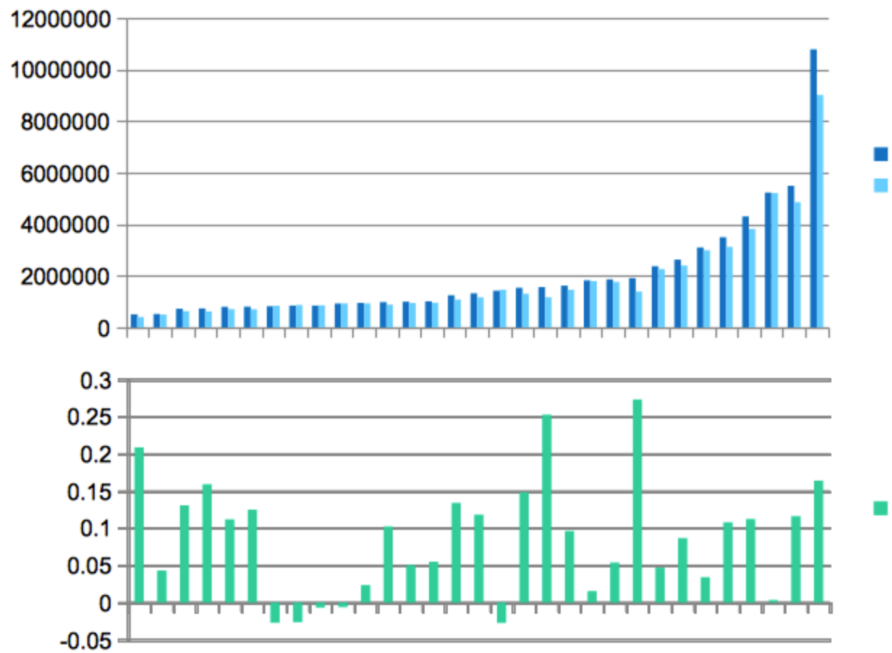
ASAR WS (15.07.2007)

ALOS PALSAR (14.07.2007)

L-band (HV, 16 m) versus C-band (VV, 75 m nominal resolution)

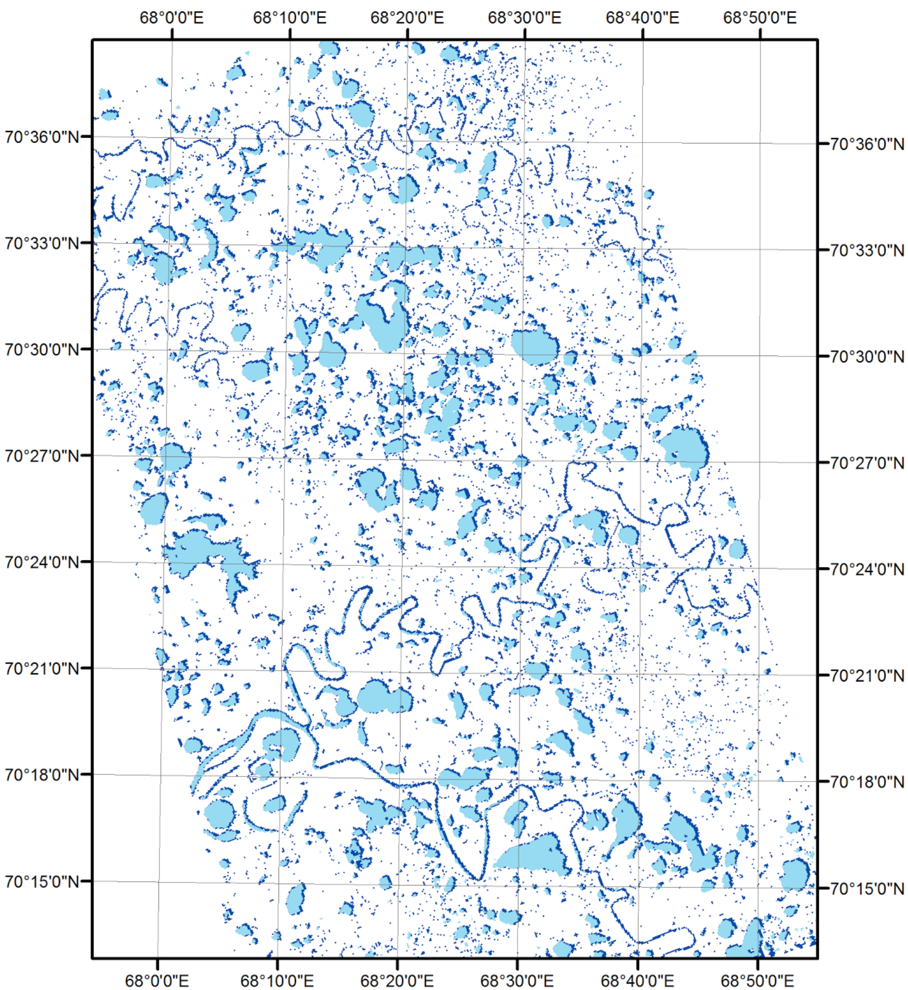
PALSAR vs. ASAR WS

Comparison of ALOS PALSAR and ASAR WS open water extent by lake size



PALSAR - ASAR [%}

Assessment of wavelength impact and lake size



b)

water bodies

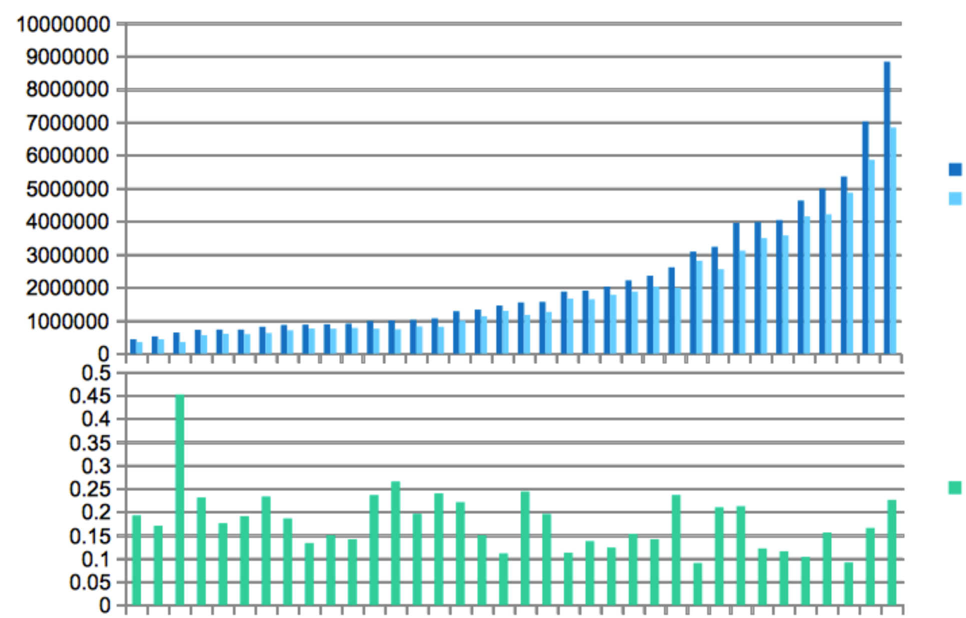
ASAR WS (13.08.2008)

TSX (13.08.2008)

X-band (HH, 5m) versus C-band (VV, 75 m nominal resolution)

TerraSAR-X vs. ASAR WS

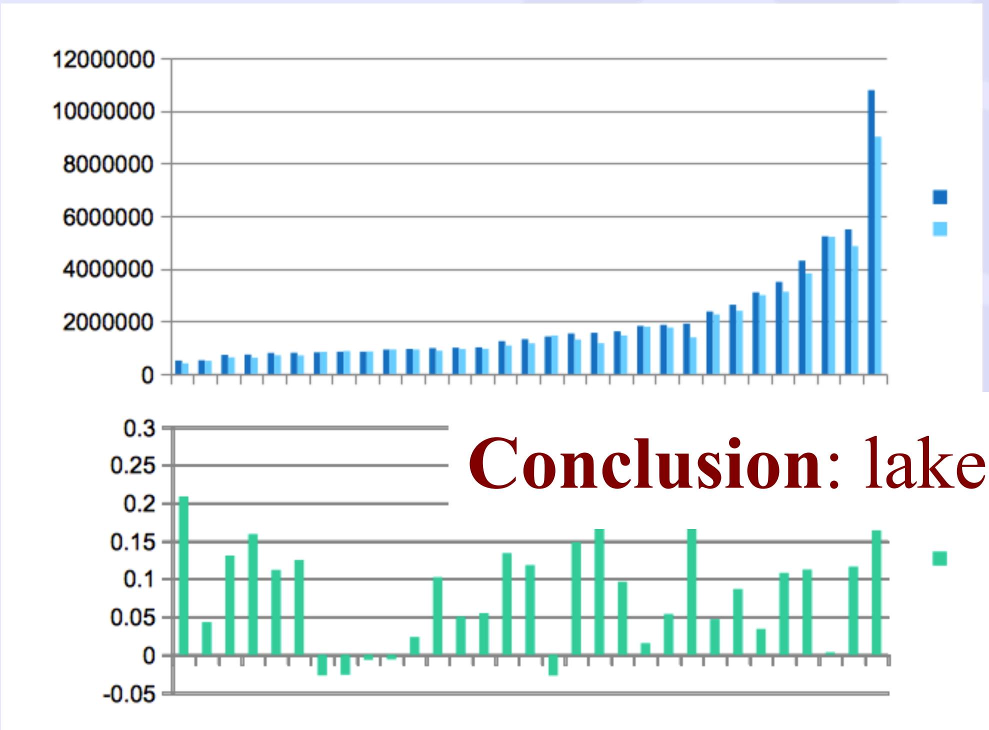
Comparison of TerraSAR-X and ASAR WS open water extent by lake size



TerraSAR-X - ASAR [%]

Assessment of wavelength impact and lake size

Comparison of ALOS PALSAR and ASAR WS open water extent by lake size



a) PALSAR - ASAR [%]

PALSAR vs. ASAR WS

L-band (HV, 16 m) versus C-band (VV, 75 m nominal resolution)

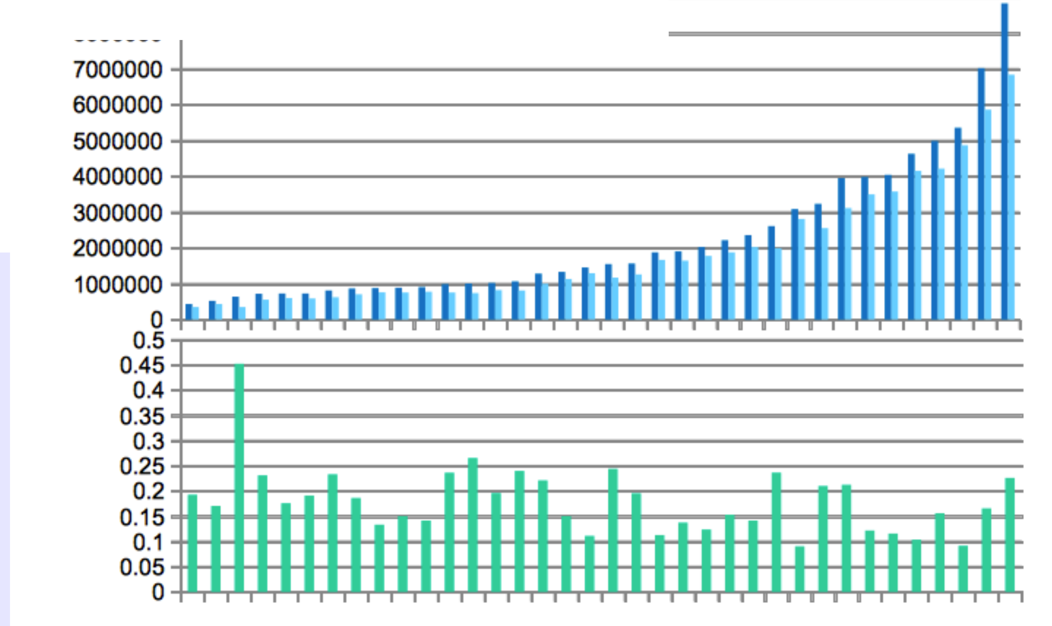
b)

X-band (HH, 5m) versus C-band (VV, 75 m nominal resolution)

TerraSAR-X vs. ASAR WS

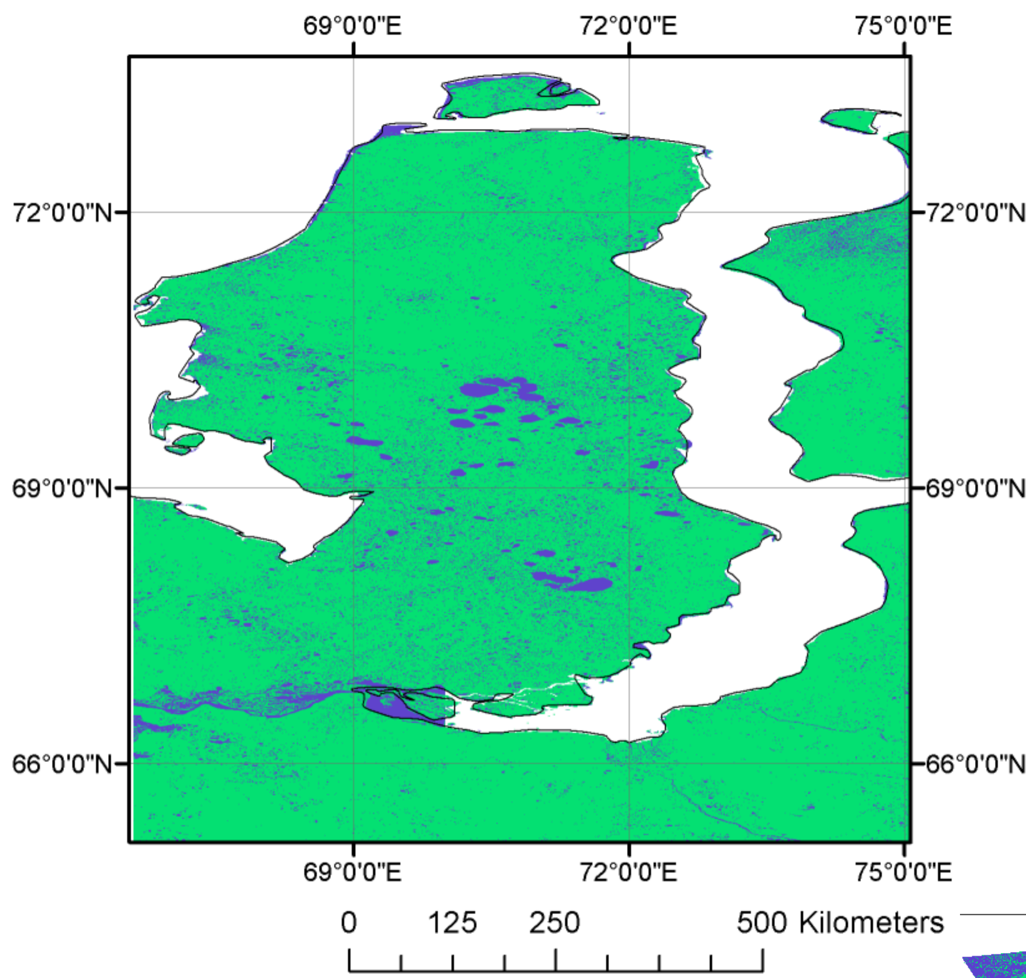
Comparison of TerraSAR-X and ASAR WS open water extent by lake size

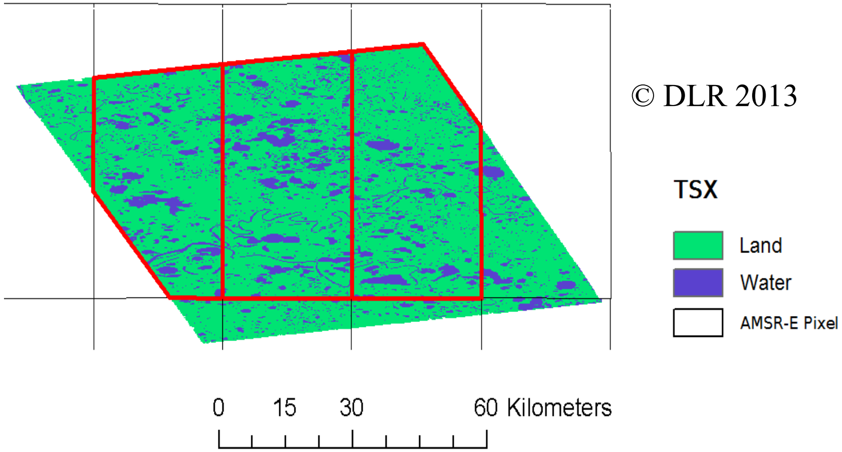
Conclusion: lake size does not matter

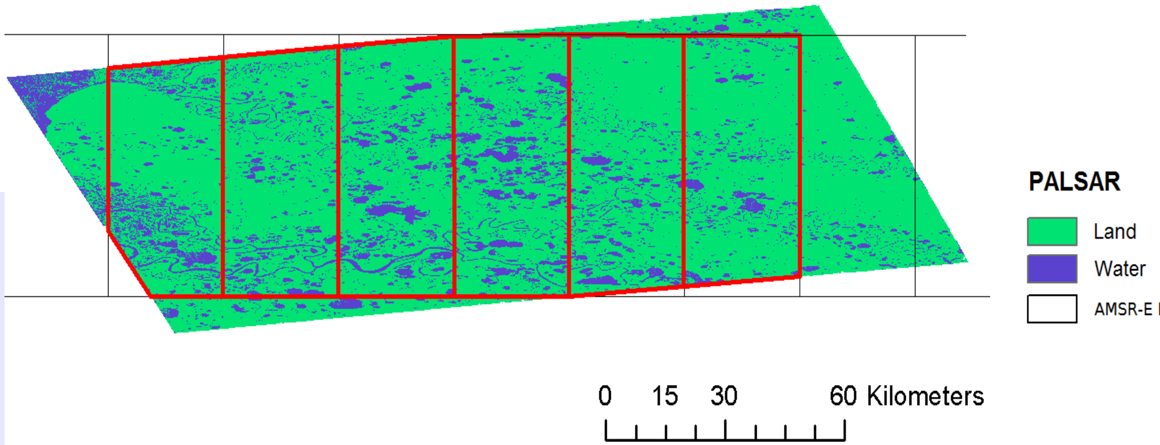


TerraSAR-X - ASAR [%]

Assessment of coarse and fine resolution data sets:

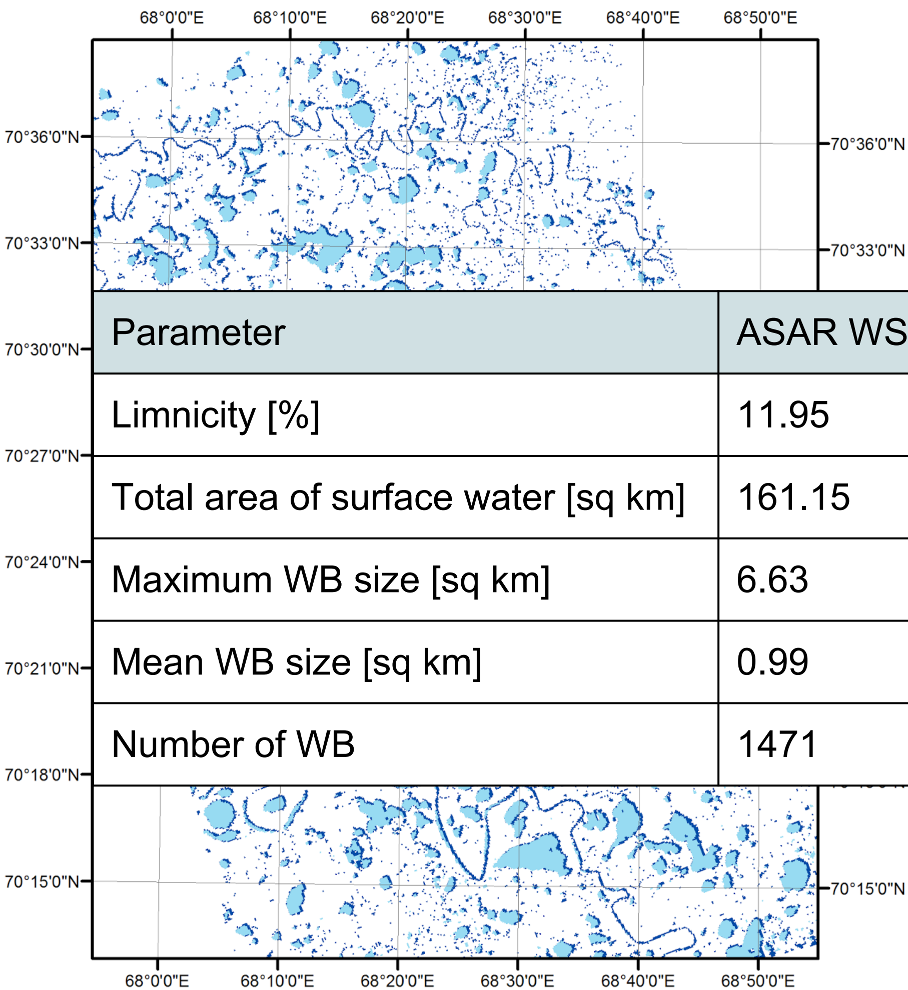






Assessment of coarse and fine resolution data sets:

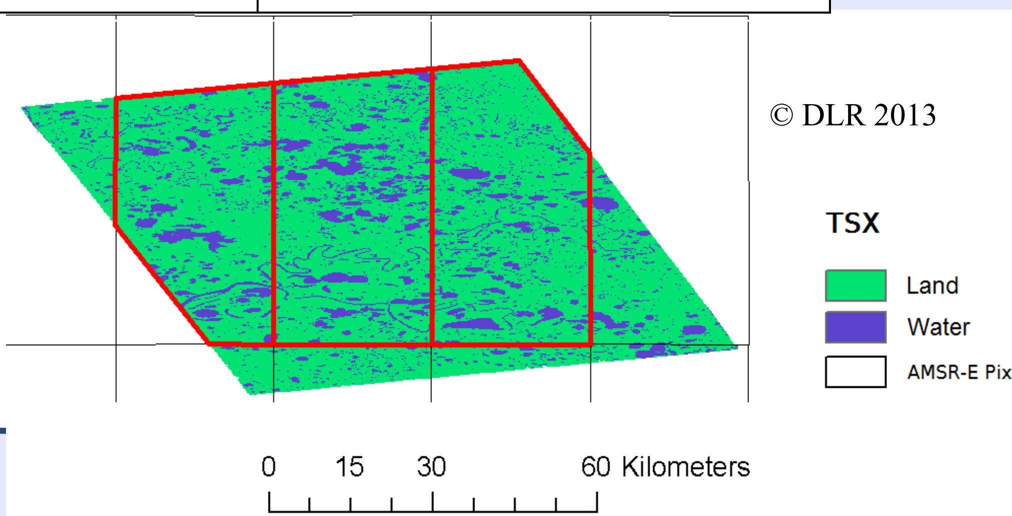
TerraSAR-X vs. ASAR WS



b)
water bodies
ASAR WS (13.08.2008)
TSX (13.08.2008)

X-band (HH, 5m)
versus C-band (VV,

Parameter	ASAR WS	TerraSAR-X
Limnicity [%]	11.95	20.03
Total area of surface water [sq km]	161.15	251.88
Maximum WB size [sq km]	6.63	8.31
Mean WB size [sq km]	0.99	0.29
Number of WB	1471	7384

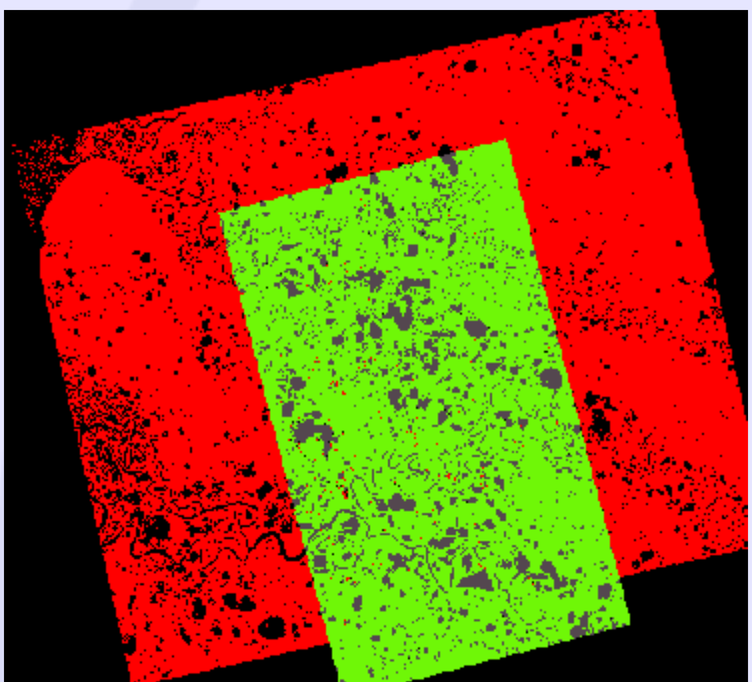


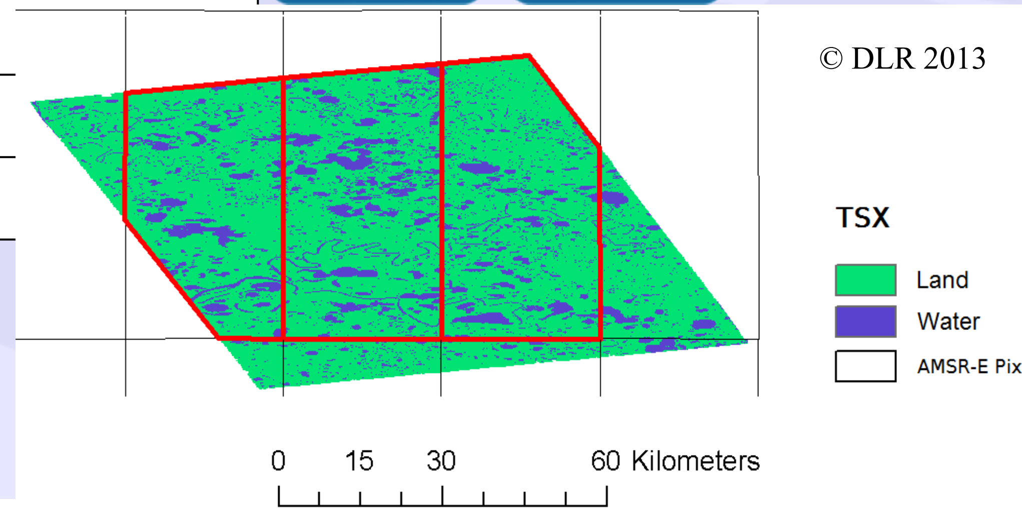
Scott Polar Research Institute
University of Cambridge

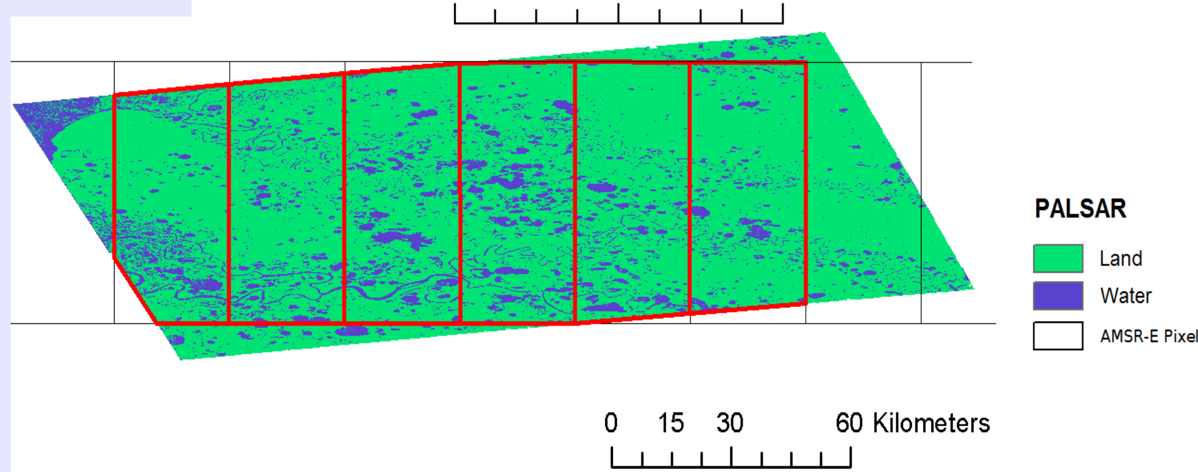
Assessment of coarse and fine resolution data sets:

Parameter	TerraSAR-X	PALSAR
Limnicity [%]	15.5	16.6
Total area of surface water [sq km]	231.26	243.82
Maximum WB size [sq km]	8.3	8.3
Mean WB size [sq km]	0.01	0.04
Number of WB	21108	6872

TerraSAR-X vs. PALSAR







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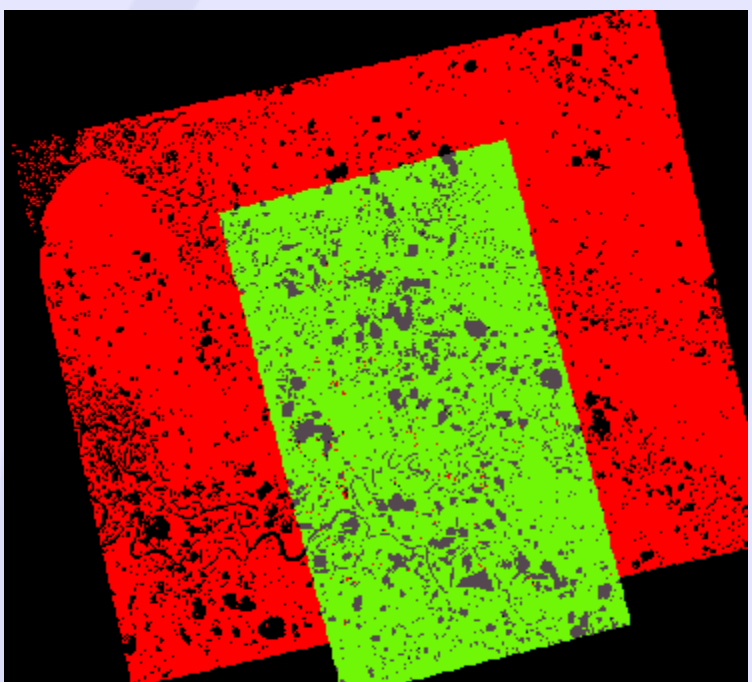
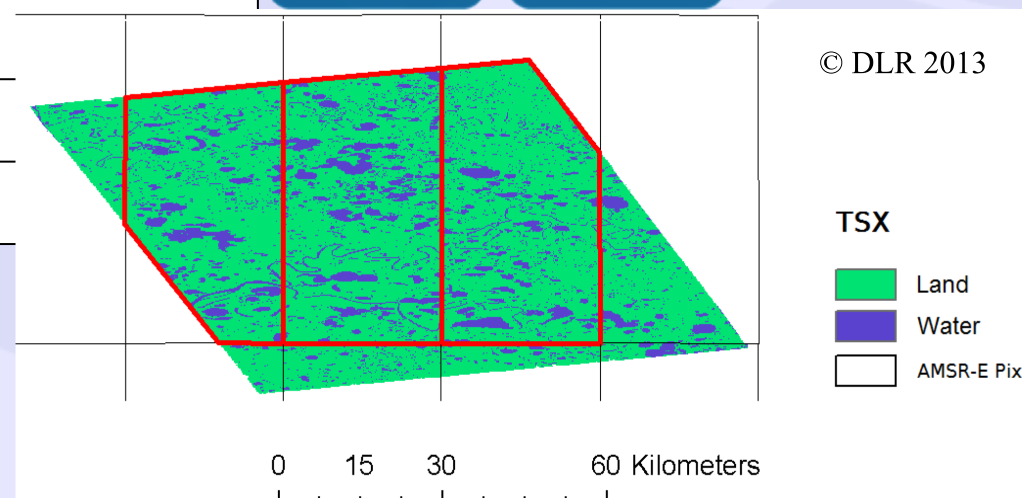
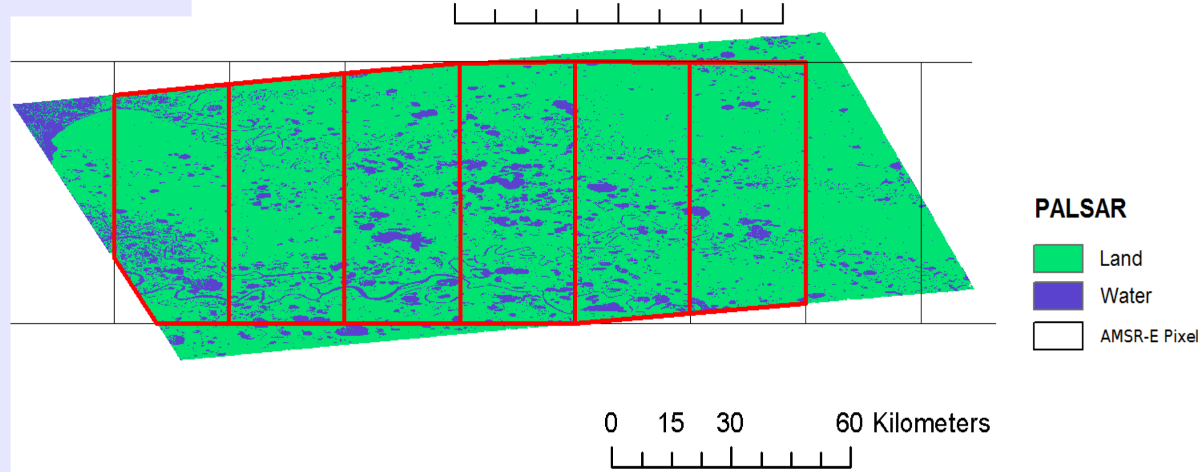
TerraSAR-X
vs.
PALSAR







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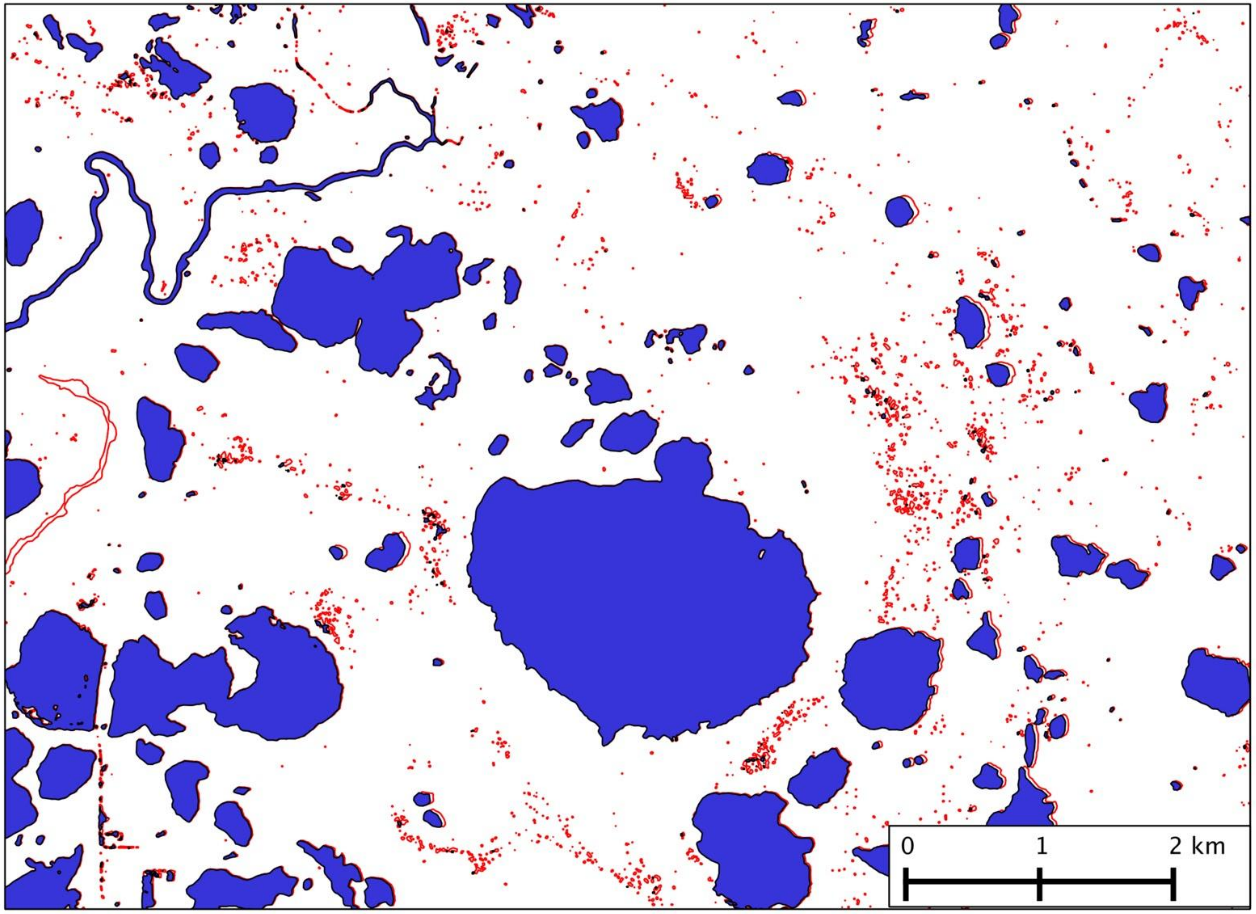
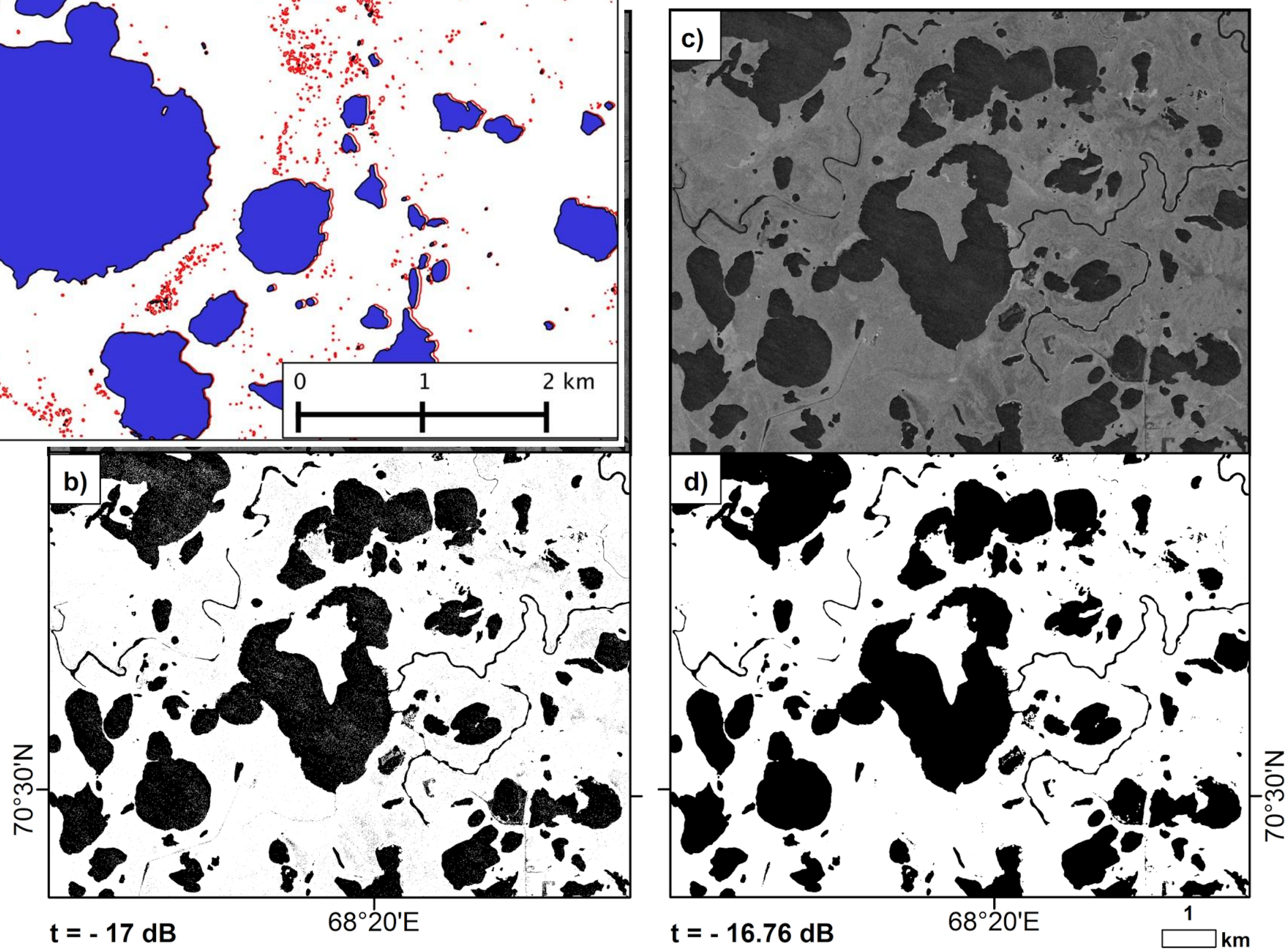
TU are looking at smaller area to compare to PALSAR



Blue: mine (additional post-classification steps incl. Speckle filter)

Red: Barbara in Vienna



Subtle differences due to threshold values.

Parameter	TerraSAR-X	PALSAR
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How come TerraSAR-X captures less surface water than PALSAR?

TerraSAR-X: X-band (HH, 5m spatial resolution)
ALOS PALSAR: L-band (HV, 16 m spatial resolution)

Parameter	TerraSAR-X	PALSAR
Limnicity [%]	15.5	16.6
Total area of surface water [sq km]	231.26	243.82
Maximum WB size [sq km]	8.3	8.3
Mean WB size [sq km]	0.01	0.04
Number of WB	21108	6872

How come TerraSAR-X captures less surface water than PALSAR?

TerraSAR-X: X-band (HH, 5m spatial resolution)
ALOS PALSAR: L-band (HV, 16 m spatial resolution)

Vegetation!

Conclusions

Lake monitoring is possible at low spatial resolution AND is needed to monitor seasonal lake and wetland dynamics – example Yamal peninsula:

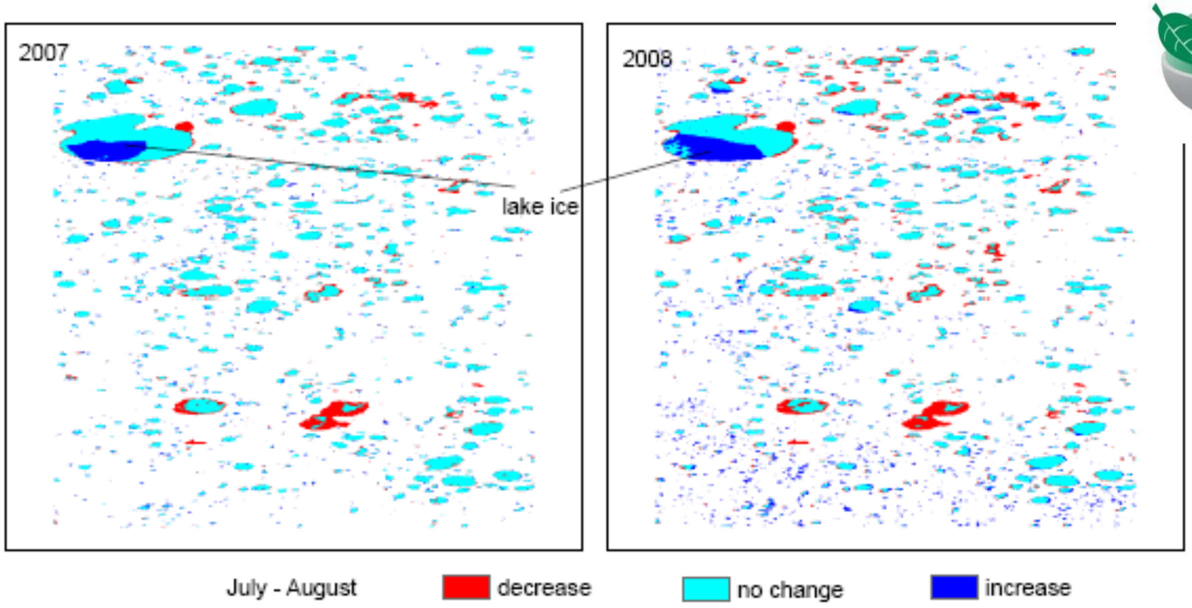

Fig. 5. Example for seasonal changes of open water extent in tundra (within a 0.5 degree cell): left – 7 July 2007 to 28 August 2007, right – 6 July 2008 to 21 August 2008.

alanis methane
support to science element

Bartsch et al., 2012
Trofaier et al. 2013

HOWEVER, need to be careful when classifying lakes due to emergent vegetation over the growing season.